CORRELATION OF BACKSCATTER WITH BOTTOM TOPOGRAPHY

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Abstract Practical data from low frequency sonar operations in shallow water has been analysed to demonstrate that a high degree of correlation exists between the received signal due to bottom backscattering and the bottom gradient in the direction of propagation, and that the relationship is in close agreement with Lambert's Law for very shallow grazing angles. Results of preliminary studies are presented which show that this relationship may be used to calculate bearing errors in towed underwater systems.

1. Introduction

During trials of an active towed array sonar (ATAS) in water of around 100 metres average depth, it was observed that consistent echoes were obtained from areas of the sea bed out to the maximum display range of the sonar (32 kms).

Strong, discrete echoes from rocky outcrops on the seabed could be easily identified by reference to the chart, but lower amplitude returns, with similar consistency, were not readily attributable, although correlation with the bottom gradient along the direction of transmission was suggested.

Similar results were reported by Revie et al [1] in his analysis of sonar operations in the Bristol Channel, where gradients as low as 1/125 gave rise to consistent echoes at ranges of almost 70km.

In an attempt to quantify, explain and possibly exploit this phenomenon, sonar returns from ranges out to around 20km have been systematically compared with detailed bathymetry of the area.

Section 3 of this paper addresses the mechanism giving rise to the observed results and proposes an explanation which is evaluated in Section 4 with practical evidence. The results of the investigation have been applied to the operational problem of bearing error evaluation in a towed sonar, results of which are presented in Section 5.

2. Data Collection

2.1 Sonar Data

The sonar data used in this study was gathered by the ATAS system which is shown diagramatically in Figure 1. The relevant system parameters are:

Frequency:	3kHz
Source Level:	219dB re 1µPa @ 1m
Transmit beamwidth:	Horizontal = 360°, Vertical = 25°
Receiver beamwidth:	5° at broadside, with automatic port/starboard discrimination
Transmitted pulse:	Linear period modulation 1s/100Hz Repetition Interval: 60s

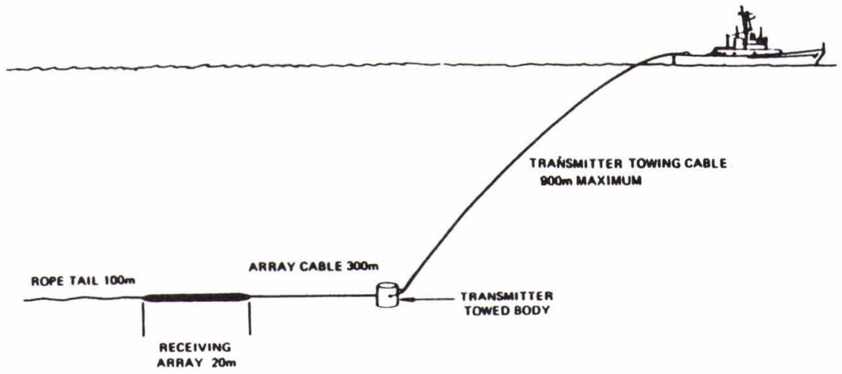


FIGURE 1 : SONAR CONFIGURATION

2.2 Environmental Data

The sonar data was gathered in December in the North Minch in calm conditions (sea state 2) following a period of higher sea-state over several days. It is therefore assumed, in the absence of a measured sound velocity profile, that water conditions were approximately isothermal. Sonar performance was consistent with this assumption.

2.3 Bathymetry Data

Detailed bathymetry data was obtained from survey data on a scale of 1:25,000 supplied by The Hydrographer, with soundings at intervals of one to two hundred metres increasing in density in the vicinity of significant features. Approximately 20,000 points were manually entered into a digital data base using a digitising table. The trial area, with contours at 10 metre intervals is shown in Figure 2 together with an isometric view of the sea-bed looking to the South East from the sonar position. In this projection the vertical scale is magnified by a factor of 100 compared with the horizontal scale.

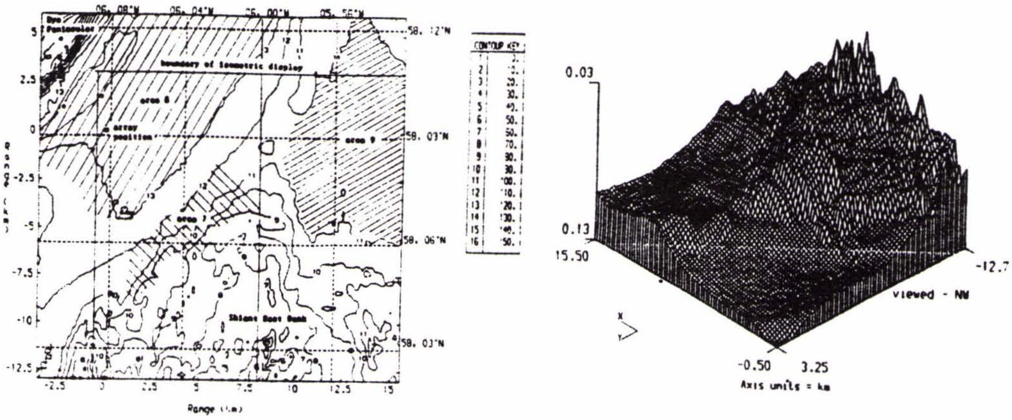


FIGURE 2 : TRIAL AREA

3. Theory

Long range propagation of acoustic energy in shallow water is only likely to be achieved along those paths which are not subjected to multiple surface and bottom reflections with their attendant losses. It may therefore be assumed that long range returns from the sea-bed will be from energy which is incident at very low grazing angles.

Analysis of the trial environment by ray plotting, assuming isothermal conditions, constant water depth of 100 metres and the sonar at a depth of 50 metres, reveals that the grazing ray at the sea-bed is that launched at 2° below the horizontal, whilst the ray at 4° below horizontal experiences a total of twelve bottom bounces in the two-way path to a range of 16km. The energy available to produce significant backscatter from the sea-bed therefore lies within the range of grazing angles from 0 to around 2°.

The value of bottom scattering strength published in general literature varies from a simple variation with bottom type, which results in a -30 log (range) dependence to a value which includes dependence on grazing angle and which usually approaches a constant value at angles of less than 20°.

Theory suggests that the scattering strength should vary in accordance with Lambert's Law, expressed as:

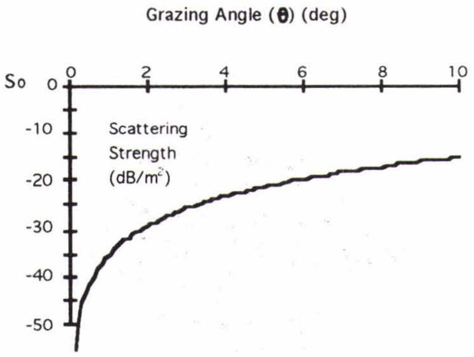
$$S = S_0 + 20 \log (\sin \theta) \ \mathrm{dB/m^2} \qquad (1)$$

where θ = grazing angle
S_0 = scattering strength at normal incidence

Differentiating equation (1):

$$\frac{dS}{d\theta} = \frac{20}{\tan \theta} \, \frac{\log e \, \pi}{180} \qquad (2)$$

Equations (1) and (2) are plotted in Figures 3 and 4.



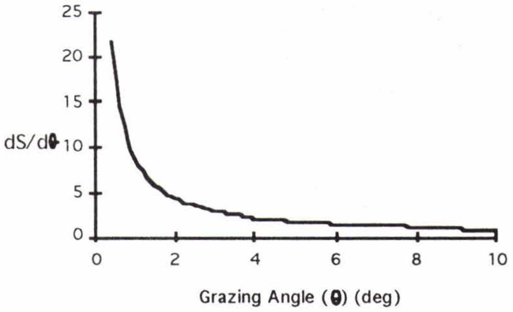


FIGURE 3 : LAMBERT'S LAW

FIGURE 4 : dS/dθ v. θ

The significance of these graphs is that whilst the value of S is very much reduced at low grazing angles, the rate of change becomes very high. Thus, at long ranges, in shallow water, the backscattered signal will be strongly dependent on the grazing angle which in turn will be primarily determined by the gradient of the sea bed. A correlation would therefore be expected between the backscattered signal strength and bottom gradient.

The effect is shown in Figure 5 where Reverberation Level (RL) is plotted as a function of range with perturbations caused by local bottom gradients of one to three degrees. Such variations would normally be eliminated from a sonar display by the relatively short normalisation period.

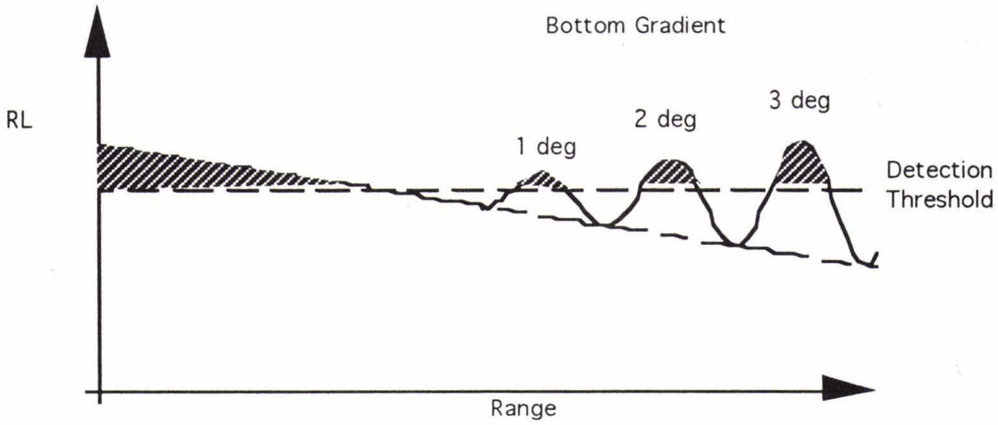


FIGURE 5 : REVERBERATION LEVEL VARIATIONS DUE TO BOTTOM GRADIENTS

4. Practical Evaluation

The hypothesis in Section 3 was tested by analysing the received signal from three successive transmissions. Un-normalised, post-correlator data was used in order to preserve the variations with range which were fundamental to this study, with a threshold of 9dB above the ambient noise level.

Using sonar parameters and a transmission loss law derived from the AGC response of the sonar, and assuming that all received signals originated as bottom backscatter, an equivalent bottom scattering strength value was calculated for each range/bearing cell over the trial area.

Visual comparison of the distribution of scattering strength with the distribution of bottom gradient in the direction of transmission showed very strong correlation throughout the area both in areas of relatively steep gradients and in areas which were essentially flat.

Figure 6 shows the variation of calculated scattering strength as a function of bottom gradient for each of the three pusles (derived from approximately 33,000 samples per pulse), together with the theoretical Lambert's Law from Figure 2. The plotted results show good agreement between the three transmissions and with Lamberts' Law over the range from 0 to 1°. The number of samples at gradients above 2° was too small to be statistically reliable.

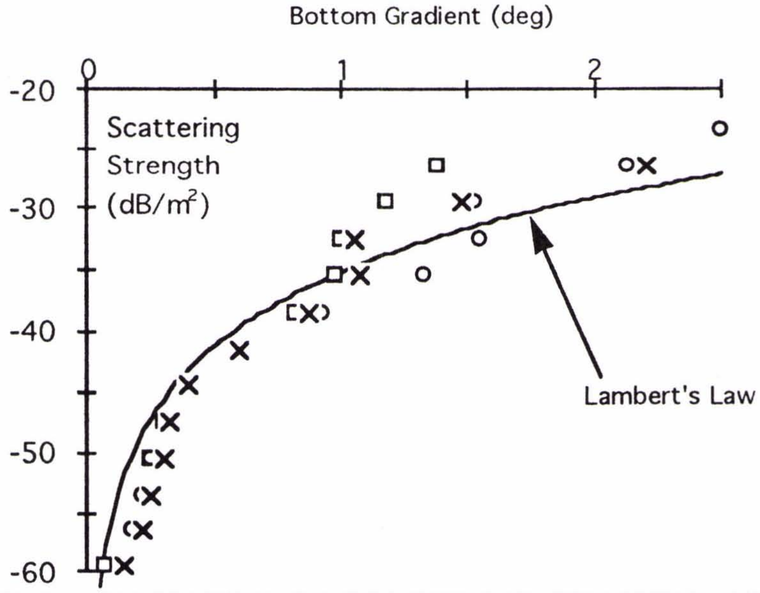


FIGURE 6 : VARIATION OF SCATTERING STRENGTH WITH BOTTOM GRADIENT

5. Correlation Function

The relationship investigated in Section 4 shows high correlation between the back-scattered signal strength and bottom gradient.

The correlation function, evaluated from

$$C(\emptyset) = \frac{1}{N} \sum_{i=1}^{N} [\text{Gradient } (i, \emptyset) \times \text{Scattering Strength } (i)]$$

Where N = No. of range/bearing cells within the area
Ø = bearing offset

may be expected to peak when the two sets of data are precisely aligned and conversely to be lower than the peak when misaligned in either range or bearing, or both.

The function has been evaluated for two cases, the first using an area of 1.2km in range and 6° in azimuth, at a range of 17km, containing a prominent bottom feature and the second using an area of 3.8km in range and 36° in azimuth, at a range of 9km, with no significant features. The results are shown in Figures 7 and 8. Both cases exhibit a well defined peak offset from zero by an amount which may be interpreted as the bearing error in the sonar data. The correlation peak is broader in Figure 8 as would be expected from the greater horizontal dimensions of the features (lower spatial bandwidth and broader autocorrelation function).

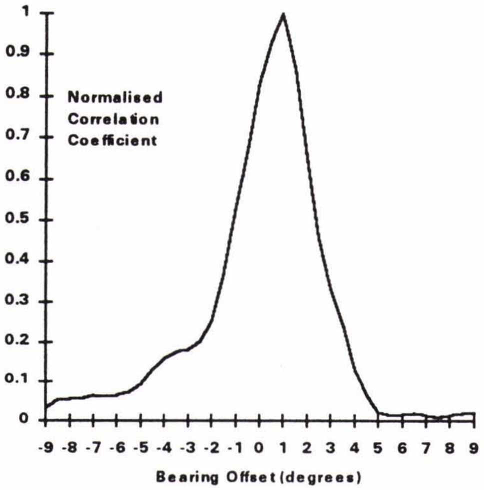


FIGURE 7 : CORRELATION FUNCTION FOR SMALL AREA WITH PROMINENT FEATURE

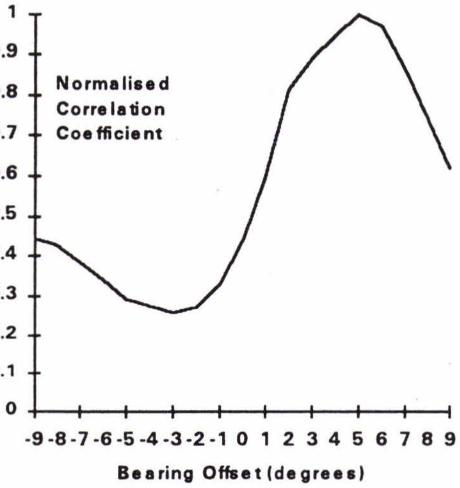


FIGURE 8 : CORRELATION FUNCTION FOR LARGER AREA

6. Observations

The results in Section 4 show good agreement between the inferred value of bottom scattering strength and bottom gradient and support the theoretical hypothesis of Section 3. It is very probable that a similar correlation could be established between bottom gradient and bottom type on the grounds that harder rocks will support steeper gradients. The reported results may be influenced by this factor although the bottom is reported as mud and sand over most of the trial area, and in practice this information is unlikely to be available in sufficient detail to separate the two variables.

The use of the correlation function in Section 5 to evaluate misalignment of sonar bearing data offers a potential solution to the problems caused by lack of knowledge of the precise position of a towed sonar system relative to the towing platform. This principle could easily be extended to produce range and bearing corrections as a function of time. In the absence of a detailed data base of bathymetry, which will frequently be the case, cross-correlation of returns from successive transmissions could provide temporal variations of range and bearing.

7. Conclusions

It has been demonstrated that, in shallow water, a strong correlation exists between the level of backscattered sonar returns from the sea-bed and the bottom gradient in the direction of propagation, at shallow grazing angles. The relationship is in close agreement with Lamberts' Law.

The results have been successfully used to demonstrate the principle of evaluating bearing error in the towed sonar system.

8. Acknowledgements

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References

1. Revie, J., Weston, D.E., Harden Jones, F.R. and Fox F.P. (1990) 'Identification of fish echoes located at 65km range by share-based sonar', J. Cons. int. Explor, Mer, 46: 313-324